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TITLED:

HYDRO-PNEUMATIC TENSIONER WITH STIFFNESS ALTERING SECONDARY ACCUMULATOR

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HYDRO-PNEUMATIC TENSIONER WITH STIFFNESS ALTERING SECONDARY ACCUMULATOR

BACKGROUND OF THE INVENTION

1. Field of the Invention.

[0001] This invention relates to tensioning of seabed-to-vessel marine risers. More particularly, this invention relates to tensioning the marine risers with a plurality of pneumatic or hydraulic cylinders.

2. Brief Description of the Related Art.

[0002] A problem presented by offshore hydrocarbon drilling and producing operations conducted from a floating platform is the need to establish a sealed fluid pathway between each borehole or well at the ocean floor and the work deck of the platform at the ocean surface. A riser typically provides this sealed fluid pathway. In drilling operations, the drill string extends through a drilling riser, the drilling riser serving to protect the drill string and to provide a return pathway outside the drill string for drilling fluids. In producing operations, a production riser is used to provide a pathway for the transmission of oil and gas to the work deck.

[0003] The riser is projected up through an opening referred to as a moon pool in the vessel to working equipment and connections proximate an operational floor on the vessel. A riser pipe operating on the floating vessel in water depths greater than about 200 feet (34.72 meters) can buckle under the influence of its own weight and the weight of drilling fluid contained within the riser if it is not partially or completely supported. For floating platforms, a special piece of equipment known as a "riser tensioner" is required to maintain each riser within a range of safe operating tensions as the work deck moves relative to the upper portion of the riser. If a portion of the riser is permitted to go into compression, it could be damaged by buckling or by bending and colliding with adjacent risers. It is also necessary to ensure that the riser is not over-tensioned when the vessel hull moves to an extreme lateral position under extreme wave conditions or when ocean currents exert a significant side loading on the riser.

[0004] A tension leg platform ("TLP") is a type of marine structure having a buoyant hull secured to a foundation on the ocean floor by a set of tethers. The tethers are each attached to the buoyant hull so that the hull is maintained at a significantly greater draft than it would assume if free floating. The resultant buoyant force of the hull exerts an upward loading on the tethers, maintaining them in tension. The tensioned tethers limit vertical motion of the hull, thus substantially restraining it from pitch, roll and heave motions induced by waves, currents and wind. However, unlike conventional platforms which are rigidly attached to the subsea floor, TLPs are not designed to resist horizontal forces induced by waves.

[0005] The marine risers have been tensioned in various manners, including the use of counterweights and pneumatic spring systems. The counterweight was the first technique utilized to apply tension to the top of the marine riser. The weight was hung from a wire rope which was run up through wire rope sheaves and down to an upper portion of the riser pipe. The tension was equal to the counterweight and therefore was practicable only for shallow water that required low tension.

[0006] The pneumatic spring systems replaced the counterweight systems as deeper water drilling evolved. The pneumatic tensioning devices stored energy in the form of compressed air to apply tension to the top of the riser through wire ropes. The pneumatic tensioning devices typically involved the use of cylinders from which a piston rod was extended, the piston rod having a sheave engaged by the wire rope to be tensioned. The fluid within the hydraulic cylinder was thereby compressed into an accumulator. The cylinder and the accumulator were normally supported by support structures on the floating vessel.

[0007] Many tensioner systems in use today act as oil-damped pneumatic springs. A large gas supply keeps a nearly constant pressure above the oil in a gas-oil accumulator. The oil then provides pressure to the face of the piston. As the vessel heaves, the piston moves up and down against a relatively constant force and the tension lines maintain a relatively constant pull.

[0008] Many riser tensioners today utilize hydraulically actuated cylinders with pneumatic pressure accumulators to provide the force necessary to maintain the upper

portion of the riser within a preselected range of operating tensions. One implementation is accomplished by the use of sheaves attached to the buoyant drilling structure whereby tensioning cables are run over the sheaves and attached to the riser so that the riser is supported by one end of the tensioning cables. The other end of each tensioning cable is connected to a piston of a hydraulic cylinder. The hydraulic cylinders are connected to a relatively large accumulator which maintains the load applied by the cylinders at a relatively constant level over the full range of travel of the pistons. Thus, as the platform moves vertically, the pistons stroke to maintain a relatively constant upward loading on the riser.

[0009] Another type of riser tensioner typically used on TLPs also uses a pneumatically pressurized fluid accumulator but eliminates the cables and sheaves used in earlier riser tensioners. Gas and oil accumulators are connected to the cylinders to control the stroke of pistons. The piston rods are directly attached to a riser tensioning ring which supports the riser.

[0010] Both classes of riser tensioning systems described generally require separate and relatively large accumulators to maintain the load applied by the cylinders with an acceptable range. Accordingly, it can be appreciated that there still exists a need for an improved riser tensioner system which provides high-capacity tension and provides for limiting peak loads while incorporating high nominal stiffness, and that does not require an excessively large accumulator.

SUMMARY OF THE INVENTION

In view of the foregoing, an embodiment of the present invention advantageously provides a tensioner unit including a barrel having a bore with pressurized fluid contained within. The barrel forms at least part of a primary accumulator having a preset volume of gas Vg1 at pressure P1. The barrel of the tensioner unit also includes an aperture to allow extension and retraction of a piston rod. The tensioner unit also includes a piston slidably carried in the bore of the barrel. The piston has a piston rod that extends from one side of the piston and through an aperture in the barrel. The piston has one of its sides in communication with the pressurized fluid, and is so positioned to increase the pressure P1 of the primary accumulator when the piston strokes in the direction of the pressurized fluid. The tensioner unit also includes a secondary accumulator housing having a bore which forms at least part of a secondary accumulator having a preset volume of gas Vg2 at pressure P2. The tensioner unit also includes a fluid separator positioned between the primary and secondary accumulators to maintain functional separation of fluid volumes of the primary and secondary accumulators when the primary accumulator pressure P1 is less than the secondary accumulator pressure P2. The fluid separator also allows functional combining of the fluid volumes of the primary and secondary accumulators when the primary accumulator pressure P1 is greater than or equal to the secondary accumulator pressure P2. The tensioner unit is configured so that when the primary accumulator pressure P1 is less than the secondary accumulator pressure P2, the effective total gas volume VgT available to the tensioner to maintain tension on a supported system, such as a riser system, is substantially equivalent to the primary accumulator gas volume Vg1. Correspondingly, when the pressure P1 is greater than or equal to the secondary accumulator pressure P2, the effective total gas volume VgT available to the tensioner to maintain tension on the supported system equals the sum of the primary accumulator gas volume Vg1 plus the secondary accumulator gas volume Vg2. This provides for reduced stiffness and reduced maximum tension applied by the tensioner unit to a supported system when the system is directing a maximum load on the tensioner unit.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] So that the manner in which the features, advantages and objects of the invention, as well as others which will become apparent, are attained and can be understood in more detail, more particular description of the invention briefly summarized above may be had by reference to the embodiment thereof which is illustrated in the appended drawings, which drawings form a part of this specification. It is to be noted, however, that the drawings illustrate only a preferred embodiment of the invention and is therefore not to be considered limiting of its scope as the invention may admit to other equally effective embodiments.

[0012] Figure 1 is a perspective view of a hydro-pneumatic tensioner system in accordance with the invention.

[0013] Figure 2 is an enlarged perspective view of one of the hydro-pneumatic tensioner units of the hydro-pneumatic tensioner system of Figure 1.

[0014] Figure 3 is a schematic view of the hydro-pneumatic tensioner unit having a first piston enclosing a second piston shown with the first piston in an extended position.

[0015] Figure 4 is a schematic view of the hydro-pneumatic tensioner unit of Figure 3, shown in a mid-point position.

[0016] Figure 5 is a schematic view of the hydro-pneumatic tensioner unit of Figure 3, shown in a retracted position.

[0017] Figure 6 is a schematic view of an embodiment of a hydro-pneumatic tensioner unit, including an internal cylinder barrel connected to an external cylinder having a second piston.

[0018] Figure 7 is a schematic view of a variation of Figure 6.

[0019] Figure 8 is a schematic view of a variation of Figure 6 having no internal cylinder barrel.

[0020] Figure 9 is a schematic view of an external cylinder for use with the tensioner unit of Figure 6, having a bladder which forms an enclosure containing a gas volume Vg2 and a hydraulic volume Vh1.

[0021] Figure 10 is a schematic view of an external cylinder for use with the tensioner unit of Figure 6, having a pilot valve interface that forms an enclosure containing a gas volume Vg2 and a hydraulic volume Vh2.

[0022] Figure 11 is a schematic view of another embodiment of a hydro-pneumatic tensioner unit, having a first piston connected to an external cylinder having a second piston, shown with the first piston in an extended position.

[0023] Figure 12 is a schematic view of the hydro-pneumatic tensioner unit of Figure 11, shown with the first piston in a mid-point position.

[0024] Figure 13 is a schematic view of the hydro-pneumatic tensioner unit of Figure 11, shown with the first piston in a retracted position.

[0025] Figure 14 is a schematic view of an external cylinder for use with the tensioner unit of Figure 11, having a bladder which forms an enclosure containing a gas volume Vg2.

[0026] Figure 15 is a schematic view of an external cylinder for use with the tensioner unit of Figure 11, having a pilot valve interface that forms an enclosure containing a gas volume Vg2.

[0027] Figure 16 is a schematic view of a variation of Figure 7.

[0028] Figure 17 is a schematic view of a pull-type hydro-pneumatic tensioner unit having a first external cylinder hydraulically connected to the hydraulic side of a first piston.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0029] The present invention will now be described more fully hereinafter with reference to the accompanying drawings which illustrate embodiments of the invention. This invention may, however, be embodied in many different forms and should not be construed as limited to the illustrated embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like elements throughout, and the prime notation, if used, indicates similar elements in alternative embodiments.

[0030] Referring to Figure 1, shown is a hydro-pneumatic riser tensioner system 20 for maintaining a riser system within a range of safe operating tensions as a work deck or platform moves relative to the upper portion of the riser system. The system 20 advantageously provides a methodology for incorporating high nominal stiffness while limiting peak loads at extreme up and down strokes. More specifically, the system 20 includes a riser system 22, extending between a floating vessel having an operational platform 24, 26, and the sea bottom (not shown).

[0031] The riser system 22 is supported in tension at its upper end to prevent the riser system 22 from buckling due to its own weight. The upward tension is maintained within acceptable limits over a typical platform deviation range by the hydro-pneumatic riser tensioner system 20. The riser tensioner system 20, discussed in detail below, includes a plurality of hydro-pneumatic tensioner units 28. The tensioner units 28 include a main body or housing 30, typically tubular shaped, stationarily located between support frames 24, 26, of a support module 23. Each tensioner unit 28 includes a hydro-pneumatic ram tensioner piston rod 32 attached at its upper end to a riser tensional mount or top plate 34, which includes a riser tensional ring 36. The riser tensional ring 36 engages a tension joint 38 of the riser system 22. The hydro-pneumatic ram tensioner piston rod 32 telescopes relative to housing 30 in response to movement of the operational platform.

[0032] Referring now to Figures 1 and 2, in a typical implementation of the hydro-pneumatic tensioner system 20, typically each hydro-pneumatic tensioner unit upper

section is attached to the top plate 34 and the lower section is connected to the support module lower support frame 24, with each unit 28 protruding through an aperture 27 in the upper support frame 26 of the support module 23. In this implementation, the riser system 22 includes a riser conductor 42 and roller assemblies 44, on lower and upper support frames 24, 26, of the support module 23 to provide for axial movement of the support module 23 with respect to the riser system 22.

[0033] In this embodiment, as the support module 23 shifts position with respect to the riser system 22, the riser system 22 slides up and down through the roller assemblies 44 and is engaged with tension from the hydro-pneumatic riser tensioner system 20 through the tensioner units 28 applying tension to the top plate 34. The top plate 34 via the mounting ring 36 translates the tension from the tensioner units 28 to the tension joint 38 of the riser system 22.

[0034] Referring now to Figures 2 and 3, as stated, the hydro-pneumatic riser tensioner system 20 includes a plurality of hydro-pneumatic tensioner units 28. Each of the units 28 has an upper end and a lower end. The upper end can include a rod end cap 46. The rod end cap 46, and thus the upper end of each unit 28 can be connected to the top plate 34 (Figure 1) to provide the requisite tension to the tension ring 36 (Figure 1) and thus to the riser system 22. The rod end cap 46 is shown as threadingly attached to a shoulder or flange 48 formed of or attached to the main body of piston rod 32, using a plurality of bolts 50, each affixed in a bolt cavity (not shown), however, any appropriate attachment or sealing methodology as known by those skilled in the art is appropriate and within the scope of the invention. In an embodiment, the lower end of the tension unit 28 is connected to the operational marine platform (not shown). In another embodiment, the lower end of the units 28 is connected to a lower platform or frame 24 of a hydro-pneumatic tensioner support module 23 (Figure 1).

[0035] Referring to Figure 3 for illustrative purposes only, generic to embodiments, described below, the tensioner unit 28 includes a barrel such as inner cylinder barrel 60 or main body 30 each having a bore and an aperture on at least one end and having a pressurized fluid contained within. The barrel forms at least part of a primary

accumulator having a preset volume of gas Vg1 at pressure P1. A piston such as piston 72 is slidably carried in the bore of the barrel. The piston has a piston rod that extends from a side of the piston and through the aperture of the barrel. One side 82 of the piston 72 is in communication with the pressurized fluid. The piston 72 is positioned to increase pressure P1 of the primary accumulator when the piston 72 strokes in the direction of the pressurized fluid. A secondary accumulator housing, such as the piston rod 32 with inner bore 76 or the external housings shown in Figure 9 or 12-15 (described later) form at least part of a secondary accumulator having a preset volume of gas Vg2 at pressure P2. A fluid separator, such as floating piston 92 (Figure 3), or the bladder or valve arrangement shown in Figures 9-12 (described later), is positioned between the primary and secondary accumulators to maintain functional separation of fluid volumes of the primary and secondary accumulators when the primary accumulator pressure P1 is less than the secondary accumulator pressure P2, and to allow functional combining of the fluid volumes of the primary and secondary accumulators when the primary accumulator pressure P1 is greater than or equal to the secondary accumulator pressure P2. This arrangement results in an effective total gas volume VgT available to the tensioner 28 to maintain tension on a supported system, such as a riser system, to substantially equal the primary accumulator gas volume Vg1 when the primary accumulator pressure P1 is less than the secondary accumulator pressure P2, and to substantially equal the sum of the primary accumulator gas volume Vg1 plus the secondary accumulator gas volume Vg2 when the pressure P1 is greater than or equal to the secondary accumulator pressure P2. The specific details of the various embodiments implementing the above described are further introduced below.

[0036] Referring to the embodiment shown in Figure 3, tensioner unit 28 includes a primary accumulator 52. The primary accumulator 52 includes an upper end having a piston seal housing aperture 54, a lower end preferably including an endcap 56 (Figure 2), and a main body 30 having an axial bore 58, therebetween. The combination, as described, along with internal components, described below, form an enclosure. The primary accumulator 52 contains a gas volume Vg1 and a hydraulic volume Vh1. Also in an embodiment, the lower end cap 56 (Figure 2) is threadingly connected within a lower end bore (not shown), although any appropriate attachment or seal means as known by

those skilled in the art is acceptable and within the scope of the invention. The sealed enclosure of the primary accumulator 52 forms a gas and hydraulic fluid reservoir. A charging connection (not shown) can be interfaced with the main body 30 of the accumulator 52 to permit intermittent or continuous charging of both the gas and hydraulic volumes Vg1, Vh1, from an external pressure source (not shown).

[0037] Referring to Figures 3-5, the hydro-pneumatic riser tensioner system 20 (Figure 1) also can include a stationery or internal cylinder barrel 60 located within the primary accumulator 52. The cylinder barrel 60 is secured sealingly to aperture 54 of accumulator 52. The cylinder barrel 60 includes an upper end having an upper piston rod aperture 62, a lower end having a lower fluid inlet aperture 64, and a main body having an axial inner bore 66, therebetween. In the preferred embodiment, the cylinder barrel 60 includes a lower fluid aperture channel extension 68 which protrudes to a position adjacent the lower end of primary accumulator 52, and provides for fluid communication between the cylindrical barrel inner bore 66 and primary accumulator hydraulic volume Vh1. The length of aperture channel extension 68 is generally formulated for the purpose of ensuring only hydraulic fluid entry into the cylinder barrel inner bore 66, not gas. The length of the channel extension 68 may be established depending upon the operating conditions the unit 28 will be subjected to and the desired ratio of gas Vg1 to fluid Vh1. The combination, as described, along with internal components, described below, form a partial enclosure. The cylinder barrel 60 interfaces and is thus in fluid communication through its lower aperture 68 with the primary accumulator hydraulic volume Vh1. The volume of hydraulic fluid contained within the cylinder barrel 60 is directly dependent upon the gas pressure P1 within the primary accumulator 52 and stroke position of the tensioner piston rod 32.

[0038] The tensioner 28 has a first piston assembly 70 that moves axially within barrel 60. The piston assembly 70 includes a combination first piston 72 and piston rod 32. The piston assembly 70 also includes an upper end typically interfaced with a rod end cap 46 (Figure 2), a lower end having a piston 72 including an aperture 74, and a main body therebetween including an inner bore 76. The combination, as described above and as to be described below, forms a channel which forms an enclosure of varying size depending

on primary accumulator gas pressure P1 and stroke position of the riser tensioner piston rod 32. In this embodiment, preferably the aperture 74 of piston 72 is not the same diameter as bore 76. The piston 72 has an outer diameter substantially equivalent to the inner diameter of the axial inner bore 66 of cylinder barrel 60. Also, preferably, the outer diameter of piston rod 32 is substantially equivalent to the diameter of piston rod aperture 62.

[0039] The first piston assembly 70 is slidably positioned to telescope from inside the cylinder barrel 60 to provide tension and stiffness to the riser system 22. Preferably the outer diameter of piston rod 32 is smaller than the inner diameter of cylinder barrel inner bore 66. This differential diameter between the first piston diameter/cylindrical barrel inner bore diameter and the piston rod main body diameter/piston rod aperture diameter forms a back annulus 78. The back annulus 78 is preferably vented to the atmosphere or through vent lines (not shown) following an appropriate methodology as known by those skilled in the art.

[0040] The telescopic range of the first piston 72 can be limited by stops, described below, which present an upper and lower limit for the travel of the first piston 72. In the configuration shown in Figures 3-5, the differential diameter between the piston rod 32 and first piston 72 form a shoulder 79 on the upper surface of the first piston 72 adjacent its outer circumference. The upper limit is the position where the first piston upper shoulder 79 contacts the lower surface 80 of the upper end of the cylinder barrel 60. The lower limit is a position where the lower surface 82 of the first piston 72 contacts the upper surface 84 of the bottom of the cylinder barrel 60.

[0041] The piston assembly inner bore 76 interfaces and is in fluid communication through its lower aperture 64 with hydraulic fluid in the cylinder barrel 60, which as previously stated is in communication with primary accumulator hydraulic volume Vh1. The volume of hydraulic fluid entering the piston assembly inner bore 76 adjacent its lower side is directly dependent upon gas pressure P1 within the primary accumulator 52, which is directly dependent upon stroke position of the tensioner piston rod 32. The first piston 72 includes seals 90 that slidably engage and seal the bore 66 of barrel 60.

[0042] The first piston 72, particularly, the inner bore 76, encloses a second piston 92 which form a housing for a secondary accumulator. The second piston 92, a fluid separator, has an upper and lower surface 94, 96, and a diameter that is substantially equal to the diameter of the first piston rod inner bore 76. The second piston 92 is slidably carried within the piston rod inner bore 76. In the embodiment shown, the second piston 92 includes pressure seals that slidingly engage inner bore 76. The second piston upper surface 94 in combination with the piston rod inner bore 76 form an enclosure, which along with a gas volume Vg2 and hydraulic volume Vh2, sealingly contained on the upper side 94 of the second piston 92, define a secondary accumulator 98 having a gas pressure P2. In a preferred variation, a charging connection (not shown) is located on the piston assembly 70 to permit intermittent or continuous charging of both the gas Vg2 and hydraulic volumes Vh2 from an external pressure source (not shown), depending on the embodiment implemented. In an alternative variation, the secondary accumulator 98 may include an interface (not shown) with an external accumulator (not shown) to provide added gas volume Vg2. Although Figures 3-5 show use of hydraulic volumes Vh1 and Vh2, the primary accumulator 52 and secondary accumulator 98 can be made purely of a gas having volume Vg1 and Vg2, respectively. The use of hydraulic oil or fluid is, however, preferred in this embodiment as it reduces the requirements on the first and second piston high-pressure seals.

[0043] The first piston rod inner bore 76 can also include a set of stops, 86, 88. Preferably retraction stops 86 are fixedly attached or formed of a protrusion in a position to define the maximum upper travel limit of the second piston 92 and ensure secondary accumulator 98 integrity. Extension stops 88 can be formed within either the inner bore 76 of the piston rod 72 or within or as part of the first piston aperture 74. Figures 3-5 depict the extension stop 88 as formed from part of a lower surface 82 of the first piston 72 which effectively forms the aperture 74 into a two-stage aperture within the first piston 72.

[0044] Peak loads or tension on the tensioner unit 28 occurring during a retraction and extension of the piston rod 32 are reduced due to the implementation of floating piston 92 within the piston rod 32. While the floating piston 92 is free-floating (not pegged against

a retraction or extension stop, 86, 88), the primary accumulator pressure P1 equals the same pressure P2 as in the secondary accumulator 98, and the total effective gas volume VgT of the unit is effectively increased by the gas volume Vg2 of the secondary accumulator 98. The increase in gas volume provides a slower rate of increase in gas pressure P1 due to the added volume Vg2, and also reduces the peak load or tension of a given downstroke (retraction of piston rod 32). This advantageously allows for the use of a smaller tensioner unit 28. The net effect of the inclusion of the gas volume Vg2 into the total effective gas volume VgT and its deletion when pressure P1 decreases below the preselected pressure P2 is to limit the minimum tension applied to the supported system (Figure 1) at full extension and to also limit the maximum tension applied at near full retraction.

[0045] The following, for illustrative purposes only, is a description of the operation of tensioner unit 28 on riser system of 20 according to an embodiment of the present invention as depicted in Figures 3-5. In operation, the hydro-pneumatic tensioner unit 28 maintains the riser system 22 within a range of safe operating tensions as a work deck or platform (not shown) moves relative to the upper portion of the riser system 22. The hydro-pneumatic tensioner system 20 ideally should be in a similar configuration to that shown in Figure 3. With the hydro-pneumatic tensioner system 20 properly installed, normally, the first piston 72 is established in the vicinity of the upper portion of the cylinder barrel 60, and the second piston 92 is normally established in a contact position with the lower stop 88. In this situation, pressure P1 on the lower side 96 of the second piston 92 is normally less than the pressure P2 on the upper side 94 of the second piston 92.

[0046] In a partial retraction situation, as best shown in Figure 4, normally, the first piston 72 is established in some mid-range position of the cylinder barrel 60, and the second piston 92 is still normally established in a contact position with the lower stop 88. In this situation, pressure P1 on the lower side 96 of the second piston 92 is still normally less than the pressure P2 on the upper side 94 of the second piston 92 but with a decreased pressure differential (P2-P1) maintaining that position. The total effective gas volume VgT is maintained substantially at that volume of the primary accumulator Vg1.

As the piston 72 continues to stroke down (retract) tension increases at a sufficient rate to provide sufficient support to the riser system 22.

[0047] In a near full retraction situation, as best shown in Figure 5, normally, in a situation where the first piston 72 was operating without the benefit of the added second piston accumulator 98, tension would increase rapidly. The second piston 92, however, having its own "charge" moves upward to maintain the two pressures P1 and P2 in substantial equilibrium unless the upper stop 86 is contacted. Thus, the implementation of the second piston 92, within the piston assembly 70, results in the effective amount of gas VgT being effectively increased over that of Vg1. The increase in gas volume provides a slower rate of increase in gas pressure P1 due to the added volume and also reduces the peak load of a given downstroke (retraction of piston rod 32).

[0048] Beginning now with the piston assembly 70 in a fully retracted position (not shown), whereby the pressure in the primary accumulator P1 may exceed that of the secondary accumulator 98 (piston 92 in contact with upper stop 86), as the piston 72 strokes up (extends), the pressure in the primary accumulator P1 decreases until it substantially reaches the pressure of the secondary accumulator P2. At that point, the floating piston 92 becomes evenly loaded on either side (*e.g.* Figure 5). As mentioned above, while the floating piston 92 is free-floating, the primary accumulator pressure P1 substantially equals that of the secondary accumulator P2, which results in a total effective gas volume VgT increase by the gas volume of the secondary accumulator Vg2.

[0049] Beginning at a near full retraction position, as best shown in Figure 5, in an extension situation, without the second piston accumulator 98, tensions would decrease rapidly. The second piston 92, however, having its own "charge" moves downward, maintaining the two pressures P1 and P2 in substantial equilibrium until the lower stop 88 is contacted. Thus, as stated previously, due to the implementation of a second piston 92, within the piston assembly 70, the effective amount of gas VgT is effectively increased. The increase in gas volume provides a slower rate of decrease in gas pressure due to the added volume. Once the primary accumulator pressure P1 decreases sufficiently, the second piston 92 is again established in a contact position with the lower stop 88 (*e.g.*

Figure 4). The increase in stiffness is reduced at near full retraction unless pressure P1 increases above the charging pressure of the secondary accumulator 98. The net effect of increasing the gas volume VgT at the near full retraction positioned to decrease maximum stiffness and to limit the minimum tension applied to the riser system 22 (Figure 1) at full upstroke (extension of piston rod 32).

[0050] In another embodiment of the present invention, as perhaps best shown in Figure 6, a tensioner unit 128 similar to the tensioner unit 28 described with respect to Figure 3 can be modified to remove second piston 92 from bore 76 of piston rod 32. In this embodiment, the piston inner bore 176 also interfaces and is in communication through its lower aperture 164 with hydraulic fluid in the cylinder barrel 160. However, with second piston 92 removed, the pressure and any gas volume within a bore 176 of piston rod 132 is that of the primary accumulator 152. In this embodiment, the gas volume contained within main body 130 and any gas volume contained in piston rod 132 combine to form the primary accumulator gas volume Vg1. The amount of hydraulic fluid entering the piston assembly inner bore 176 adjacent its lower side is directly dependent upon gas pressure P1 within the primary accumulator 152, which is directly dependent upon stroke position of the piston rod 132. Note, although Figure 6 depicts a gas volume in the bore 176 of piston rod 132, piston rod 132 may be filled entirely with part of the hydraulic volume of the primary accumulator 152. Additionally, bore 176, at for example aperture 174, may be capped so that gas volume Vg1 is contained entirely within main body 130. Also note, if the structure described in Figure 3 were used to form this embodiment, optional features, such as upper and lower stops, 86, 88, described with respect to Figure 3 are unnecessary. If installed, however, they do not affect the functional operation of the embodiment as configured and shown in Figure 6.

[0051] In this embodiment, the tensioner unit 128 includes a secondary accumulator 121 having housing 101, separate from the cylinder barrel 160, piston rod 132, and main body 130, which interfaces and is in fluid communication through its aperture 103 with primary accumulator hydraulic fluid Vh1 (or gas Vg1) either in the cylinder barrel 160, piston rod 132, or main body 130 (as shown). Correspondingly, depending on the configuration, either cylinder barrel 160, piston rod 132, or main body 130, can have an

aperture 105 and a fluid connection assembly 107, as known and understood by those skilled in the art, to be connected to the aperture 103 of the secondary accumulator housing 101. Preferably, the secondary accumulator housing 101 is in the form of an external cylinder having an inner bore 109. In the configuration shown in Figure 6, the secondary accumulator housing 101 includes a fluid separator in the form of a floating piston 111. The inner bore 109 encloses the floating piston 111. The floating piston 111 has an upper and lower surface 113, 115, and a diameter that is substantially equal to the diameter of the secondary accumulator housing inner bore 109. The floating piston 111 can include pressure seals that slidingly engage the inner bore 109. The floating piston upper surface 113 in combination with the secondary accumulator housing inner bore 109 form an enclosure, which along with a gas volume Vg2 and a hydraulic volume Vh2, sealingly contained on the upper side 113 of the floating piston 111, define secondary accumulator 121 having a gas pressure P2. The lower side 115 of the floating piston 111 in combination with the secondary accumulator housing inner bore 109 form an additional portion of the primary accumulator 152.

[0052] In the preferred configuration, the secondary accumulator housing inner bore 109 includes a set of stops 123, 125. Retraction stops 123 are fixedly attached and form a protrusion to define a maximum upper travel limit of the floating piston 111 and ensure secondary accumulator 121 integrity. Extension stops 125 are formed within the secondary accumulator housing inner bore 109. Under normal conditions, where pressure P2 of the secondary accumulator 121 is greater than the pressure P1 of the primary accumulator 152, the floating piston 111 rests against extension stops 125. As with the embodiment depicted in Figures 3-5, the loads occurring during a retraction of the piston rod 32 are reduced due to the implementation of the floating piston 111 within the secondary accumulator housing 101. As with the embodiment described in Figure 3, either the primary accumulator 152 or the secondary accumulator 121 may include charging connections (not shown) to permit intermittent or continuous charging of both the gas volumes Vg1, Vg2, and hydraulic volumes Vh1, Vh2, from an external pressure source (not shown). In another variation, the secondary accumulator 121 may include an interface (not shown) with another external accumulator (not shown) to provide added gas volume.

[0053] In another embodiment of the present invention, as perhaps best shown in Figure 7, a tensioner unit 228 similar to the tensioner unit 128 described with respect to Figure 6 can be modified to either cap lower end 164 of cylinder barrel 160 and/or remove lower fluid aperture channel extension 168, or, as shown in Figure 7, cap channel extension 268 with cap 269. The main body 230, in this embodiment, if implemented, generally functions to provide protection and to provide an attachment point to a supported structure. As in the previous embodiment, described with respect to Figure 6, the piston inner bore 276 interfaces and is in communication through its lower aperture 274 with hydraulic fluid in bore 266 of the cylinder barrel 260. The amount of hydraulic fluid entering the piston assembly inner bore 276 adjacent its lower side is directly dependent upon gas pressure P1 within the primary accumulator 252, which is directly dependent upon stroke position of piston 272 and piston rod 232. The gas volume contained within the piston rod 232, however, in the depicted configuration, solely forms the primary accumulator gas volume Vg1.

[0054] In this embodiment, the tensioner unit 228 also includes secondary accumulator 121 having housing 101, separate from the cylinder barrel 260, piston rod 232, and main body 230 (if so configured), which interfaces and is in fluid communication through its aperture 103 with primary accumulator hydraulic fluid Vh1 in the cylinder barrel 260 (as shown). Correspondingly, cylinder barrel 260 has aperture 205 fluidly connected to fluid connection assembly 207 and to aperture 103 of the secondary accumulator housing 101. As described with respect to the embodiment shown in Figure 6, the secondary accumulator housing 101 also includes a fluid separator in the form of a floating piston 111. The inner bore 109 encloses the floating piston 111. The floating piston 111 has an upper and lower surface 113, 115, and a diameter that is substantially equal to the diameter of the secondary accumulator housing inner bore 109. The floating piston 111 can include pressure seals that slidingly engage the inner bore 109. The floating piston upper surface 113 in combination with the secondary accumulator housing inner bore 109 form an enclosure, which along with a gas volume Vg2 and a hydraulic volume Vh2, sealingly contained on the upper side 113 of the floating piston 111, define a secondary accumulator 121 having a gas pressure P2. The lower side 115 of the floating

piston 111 in combination with the secondary accumulator housing inner bore 109 form an additional portion of the primary accumulator 252.

[0055] In still another embodiment of the present invention, as perhaps best shown in Figure 8, a tensioner unit 328 similar to the tensioner unit 128 described with respect to Figure 6 can be modified to either remove inner barrel 160 or to cap the lower end 164 of cylinder barrel 160 and remove the main body (tubular housing) 130 and channel extension 168. If the inner barrel 160 is removed, the diameter of the first piston 172 can be modified so that the outer diameter of piston 372 is substantially equivalent to the inner diameter of the axial inner bore 358 of the main body or barrel 330. Correspondingly, back annulus 378 performs the same function described above and interfaces with the bore 358 of main body 330 instead of bore 166 (Figure 6) of cylinder barrel 160.

[0056] Regardless of the configuration selected, as with the previous embodiment described with respect to Figure 7, the piston inner bore 376 interfaces and is in communication through its lower aperture 374 with hydraulic fluid in the barrel housing the piston rod 332. The amount of hydraulic fluid entering the piston assembly inner bore 376 adjacent its lower side is directly dependent upon gas pressure P1 within the primary accumulator 352, which is directly dependent upon stroke position of piston 372 and piston rod 332. The gas volume contained within the piston rod 332, however, in the depicted configuration, again solely forms the primary accumulator gas volume Vg1.

[0057] Still referring to Figure 8, the tensioner unit 328 can include secondary accumulator 121 having housing 101, separate from either the main body (bore) 330 and piston rod 332, which interfaces and is in fluid communication through its aperture 103 with primary accumulator hydraulic fluid Vh1 in the main body 330. Correspondingly, the main body 330 has aperture 305 fluidly connected to a fluid connection assembly 307 and to aperture 103 of the secondary accumulator housing 101. The secondary accumulator housing 101 also includes a fluid separator in the form of a floating piston 111, which along with secondary accumulator housing 101 forms an enclosure containing a gas volume Vg2 and hydraulic volume Vh2, which define a secondary accumulator 121, as previously described, in detail, with respect to the embodiments shown in Figure

6 and Figure 7. Note, Figure 7 and 8 not only depict a possible position for a hydraulic Vh1 tap (aperture 305) but also a possible position of a gas Vg1 tap in the piston rod 332 where the secondary accumulator housing and is configured in the form of an external gas accumulator (described later).

[0058] The previous embodiments, as shown in Figures 3-8 and described above, depict the housing for a secondary accumulator in the form of either a piston rod 32 having inner bore 76 (Figures 3-5) or secondary accumulator housing 101 having inner bore 109 and containing within a fluid separator in the form of a floating piston 92, 111, sealingly engaging the inner bore 76, 109, respectively (Figures 6-8). Regarding the embodiments described with respect to Figures 6-8, the floating piston 111 sealingly and slidingly engages inner bore 109 of secondary accumulator housing 101 and functions in a similar manner as floating piston 92, described with respect to Figures 3-5 (previously described in detail). Alternative embodiments of the fluid separator in the secondary accumulator are, however, within the scope of the present invention.

[0059] For example, as best shown in Figure 9, the floating piston 111 (Figures 6-8) can be replaced by a bladder 211 that sealingly engages inner bore 209 of secondary accumulator housing 201 in a fixed position. Similar to the floating piston 111 implementation, upper surface 213 of the bladder 211 in combination with the secondary accumulator housing inner bore 209 form an enclosure, which along with a gas volume Vg2 sealingly contained on the upper side 213 of the bladder 211, define a secondary accumulator 221 having a gas pressure P2. The lower side 215 of the bladder 211 in combination with the secondary accumulator housing inner bore 209 form an additional portion of the primary accumulator through aperture 203.

[0060] In operation, bladder 211 is selected to "balloon" when pressure P1 of the primary accumulator equals or exceeds pressure P2 of the secondary accumulator. Hydraulic volume Vh1 having pressure P1 serves to compress bladder 211 at a preselected pressure P2, which, in turn, serves to compress the secondary accumulator gas volume Vg2 to substantially the same extent as that of the hydraulic volume Vh1 having pressure P1 compresses primary accumulator gas volume Vg1. This "ballooning effect" results in functionally combining the gas volume of the primary accumulator Vg1 and with the gas

volume Vg2 of the secondary accumulator when the pressure P1 of the primary accumulator equals or exceeds pressure P2 of the secondary accumulator. This results in an increased total gas volume VgT which serves to reduce maximum tension and stiffness during a downstroke of the piston rod. However, as with the configuration described with respect to Figure 9, secondary hydraulic volume Vh2 would be unnecessary. As stated above, the secondary hydraulic volume Vh2 in the above described embodiments and their corresponding configurations is generally used for the purpose of maintaining hydraulic seals of the floating piston. As the bladder 211 is fixedly mounted, the second hydraulic fluid volume is unnecessary. Note also, the second piston 92 (Figures 3-5) can be replaced by a bladder similar to bladder 211 fixedly mounted within bore 76 of piston rod 32.

[0061] As best shown in Figure 10, the floating piston 111 (Figures 6-8) can also be replaced by a fluid separator in the form of a valve or valve arrangement 311. In this embodiment of the present invention, valve arrangement 311, typically in the form of a pilot valve, has a first fluid connection assembly 343 in fluid communication with pressurized fluid in the primary accumulator through an aperture 105 (Figures 6) and a second fluid connection assembly 345 in fluid communication with the pressurized fluid contained within secondary accumulator housing 301 through aperture 303 to intermittently connect pressurized fluid in the primary accumulator with pressurized fluid in the secondary accumulator housing when pressure P1 in the primary accumulator pressure P1 equals or exceeds the preselected pressure P2 of the secondary accumulator. Referring to the configurations shown in Figures 6-8, when combined with the fluid separator shown in Figure 10, the interface between the fluid separator and the primary accumulator is with hydraulic volume Vh1. The bore 309 of secondary accumulator housing 101 contains gas volume Vg2 and hydraulic volume Vh2 which, in combination with the second fluid connection assembly 345 of the valve arrangement 311, define a secondary accumulator 321.

[0062] In operation, as primary accumulator pressure P1 equals or exceeds secondary accumulator pressure P2, the valve arrangement 331 allows a portion of hydraulic volume Vh1 to enter the secondary accumulator and compress the secondary accumulator gas volume Vg2 to substantially the same extent the hydraulic volume Vh1 having

pressure P1 compresses primary accumulator gas volume Vg1. This "effect" results to combine the gas volume of the primary accumulator Vg1 and with the gas volume Vg2 of the secondary accumulator when the pressure P1 of the primary accumulator equals or exceeds pressure P2 of the secondary accumulator. This produces an increased total gas volume VgT which serves to reduce maximum tension and stiffness during a downstroke of the piston rod. As the pressure P1 of the primary accumulator decreases to that of the preselected secondary accumulator pressure P2, the valve arrangement 311 allows substantially the same amount of hydraulic fluid from the primary accumulator hydraulic volume Vh1 equivalent to the amount that entered the secondary accumulator hydraulic volume Vh2 to be returned through the valve arrangement 311 by the expanding secondary accumulator gas volume Vg2. When the primary accumulator pressure P1 decreases below the secondary accumulator preset pressure P2, the two hydraulic volumes Vh1, Vh2, are isolated from each other by valve arrangement 311 and the total equivalent gas volume VgT of the tensioner unit is that of the primary accumulator gas volume Vg1.

[0063] As stated above, the previous embodiments shown in Figures 3-8 and described above in detail, depict a housing for a secondary accumulator combined with a fluid separator either in the form of a piston, bladder, or valve arrangement, functionally engaged through use of a primary accumulator hydraulic volume Vh1. With respect to the embodiments described that utilize a separate external secondary accumulator housing, and with reference to Figures 6-8, little modification to those embodiments need be necessary in order to provide a secondary accumulator which is functionally engaged entirely through use of a gas such as primary accumulator gas volume Vg1.

[0064] Referring to Figures 11-15, shown is the implementation of a tensioner unit 428, similar to that described with reference to Figure 7, having three variations of a secondary accumulator in the form of the gas accumulator. The tensioner unit 428 can have secondary accumulator housing 401 positioned in fluid (gas) communication with either of the previously described embodiments primary accumulator gas volume Vg1. For example, aperture 405 can be located in piston rod 432 to provide primary accumulator pressure P1 to either of the embodiments of a fluid separator, described above. Referring to the implementation of a fluid separator taking the form of a floating

piston 411 (Figures 11-13), the floating piston 411 performs the same function as floating piston 111 as described with respect to Figure 6-8 or floating piston 92 described with respect to Figures 3-5. In this configuration, however, the gas volume contained within the bore 476 of piston rod 432, lower side 415 of the floating piston 411 in combination with the secondary accumulator housing inner bore 409, and fluid connection assembly 407 positioned between apertures 403 and 405 combine to form the primary accumulator having the primary accumulator gas volume Vg1. The bore 409 of the secondary accumulator housing 401 in combination with the upper side 413 of floating piston 411 and containing secondary accumulator gas volume Vg2 form the secondary accumulator 421. Note, no hydraulic volume Vh2 is used within the secondary accumulator 421 in this configuration. Note also, due to the absence of hydraulic oil, the seals used to seal floating piston 411 in inner bore 409 of the secondary accumulator housing 401 are gas seals, otherwise the configuration within secondary accumulator housing 401 can be substantially the same as that shown in Figures 6-8.

[0065] In operation, with a supported system such as the hydro-pneumatic tensioner system 20 properly installed, normally, the first piston 472 is established in the vicinity of the upper portion of the cylinder barrel 460, and the floating piston 411 is normally established in a contact position with the lower stop 425. In this situation, pressure P1 on the lower side 415 of the floating piston 411 is normally less than the pressure P2 on the upper side 413 of the floating piston 411.

[0066] In a partial retraction situation, as best shown in Figure 12, normally, the first piston 472 is established in some mid-range position of the cylinder barrel 460, and the floating piston 411 is still normally established in a contact position with the lower stop 425. In this situation, pressure P1 on the lower side 415 of the floating piston 411 is still normally less than the pressure P2 on the upper side 413 of the floating piston 411 but with a decreased pressure differential (P2-P1) maintaining that position. The total effective gas volume VgT is maintained substantially at that volume of the primary accumulator Vg1. As the piston 472 continues to stroke down (retract) tension increases at a sufficient rate to provide sufficient support to the supported system.

[0067] In a near full retraction situation, as best shown in Figure 13, normally, in a situation where the first piston 472 was operating without the benefit of the added second piston accumulator 421, tension would increase rapidly. The floating piston 411, however, having its own "charge" moves upward to maintain the two pressures P1 and P2 in substantial equilibrium unless the upper stop 423 is contacted. Thus, the implementation of the floating piston 411 in the external secondary accumulator housing 401 provides the same function as the second piston 92 (Figures 3-5) within the piston rod 32. The implementation of the floating piston results in the effective amount of gas VgT being increased over that of Vg1. The increase in gas volume provides a slower rate of increase in gas pressure P1 due to the added volume and also reduces the peak load of a given downstroke (retraction of the piston rod).

[0068] Referring now to Figure 14, the floating piston 411 (Figures 11-13) can be replaced by a bladder 511 that sealingly engages inner bore 509 of secondary accumulator housing 501 in a fixed position. In this configuration, the gas volume contained within the bore 476 of piston rod 432, lower side 515 of the bladder 511 in combination with the secondary accumulator housing inner bore 509, and fluid connection assembly 507 connected to aperture 503 combine to form a primary accumulator having the primary accumulator gas volume Vg1. As with the floating piston 411, upper surface 513 of the bladder 511 in combination with the secondary accumulator housing inner bore 509 form an enclosure, which along with a gas volume Vg2 sealingly contained on the upper side 513 of the bladder 511, define a secondary accumulator 521 having a gas pressure P2. Note, the second piston 92 (Figures 3-5) can also be replaced by a bladder similar to bladder 511 and fixedly mounted within bore 76 of piston rod 32.

[0069] In operation, bladder 511 is selected to "balloon" when pressure P1 of the primary accumulator equals or exceeds pressure P2 of the secondary accumulator. However, in this configuration, gas volume Vg1, as opposed to hydraulic volume Vh1 having pressure P1 (Figure 9), serves to compress bladder 511 at a preselected pressure P2, which, in turn, serves to compress the secondary accumulator gas volume Vg2 to relatively the same extent as that hydraulic volume Vh1 having pressure P1 compresses

the portion of the primary accumulator gas volume Vg1 within bore 476 of piston rod 432. Where primary accumulator pressure P1 equals or exceeds the secondary accumulator pressure P2, the gas volumes Vg1, Vg2, functionally combine to produce an increased total gas volume VgT which serves to reduce maximum tension and stiffness during a downstroke of the piston rod 432. When the primary accumulator pressure P1 is again reduced below the preset secondary accumulator pressure P2, the total effective gas volume VgT returns to that of the primary accumulator gas volume Vg1, and stiffnesses to the supported unit is increased.

[0070] As best shown in Figure 15, the floating piston 411 (Figures 11-13) can also be replaced by a fluid separator in the form of an entirely gas fluid operated valve or valve arrangement 611. In this configuration, valve arrangement 611, typically in the form of a pilot valve, has a first fluid connection assembly 643 in fluid communication with pressurized fluid in the primary accumulator through aperture 405 positioned to access primary accumulator gas volume Vg2, and a second fluid connection assembly 645 in fluid communication with the pressurized fluid contained within secondary accumulator housing 601 through aperture 603 to intermittently connect pressurized fluid in the primary accumulator with pressurized fluid in the secondary accumulator housing when pressure P1 in the primary accumulator pressure P1 equals or exceeds the preselected pressure P2 of the secondary accumulator. Referring still to the tensioner unit 428 of Figure 11 combined with the secondary accumulator 621 shown in Figure 15, when the interface between the fluid separator and the primary accumulator is with gas volume Vg1, the bore 609 of secondary accumulator housing 601 contains gas volume Vg2 only which, in combination with the second fluid connection assembly 645 of the valve arrangement 611, defines the secondary accumulator 621.

[0071] In operation, as primary accumulator pressure P1 equals or exceeds secondary accumulator pressure P2, the valve arrangement 611 allows a portion of gas volume Vg1 to enter the secondary accumulator and compress the secondary accumulator gas volume Vg2 to substantially the same extent the gas volume Vg1 is compressed. This "effect" results to combine the gas volume of the primary accumulator Vg1 and with the gas volume Vg2 of the secondary accumulator when the pressure P1 of the primary accumulator equals or exceeds pressure P2 of the secondary accumulator. This produces

an increased total gas volume VgT which serves to reduce maximum tension and stiffness during a downstroke of the piston rod 432. As the pressure P1 of the primary accumulator decreases to that of the preselected secondary accumulator pressure P2, the valve arrangement 611 allows substantially the same amount of gas volume that entered the secondary accumulator to be returned through the valve arrangement 611 by the expanding secondary accumulator gas volume Vg2. When the primary accumulator pressure P1 decreases below the secondary accumulator preset pressure P2, the two gas volumes Vg1, Vg2, are isolated from each other by valve arrangement 611 and the total equivalent gas volume VgT of the tensioner unit is that of the primary accumulator gas volume Vg1.

[0072] Referring now to Figure 16, an alternative embodiment, a tensioner unit 528 similar to the tensioner unit 128 (Figure 6) is modified to prevent primary accumulator hydraulic volume Vh1 or primary accumulator gas volume Vg1 from entering either piston 572, piston rod 532, or both. This embodiment can interface with either of the secondary accumulators described with respect to Figures 6-15. In the configuration shown in Figure 16, the primary accumulator includes the inner bore of the main body (barrel) 530 and the lower surface 582 of piston 572 along with the fluid connection assembly and the primary accumulator side of the fluid separator, according to the type of secondary accumulator selected.

[0073] In a configuration where the tensioner unit 528 is implemented with a gas-type secondary accumulator, such as those described with respect to Figures 11, 14, or 15, aperture 505 is positioned in the main body 530, above the maximum hydraulic volume fluid line (not shown) corresponding to the level of the primary accumulator hydraulic volume Vh1 within the main body 530 that is external to the cylinder barrel 560 and reached when piston 572 is in full downstroke. Primary accumulator hydraulic volume Vg1 interfaces with the fluid separator of the selected secondary accumulator to effectively combine the primary accumulator gas volume Vg1 with the selected secondary accumulator gas volume Vg2. In a configuration where the tensioner unit 528 is implemented with a hydraulic-type secondary accumulator, such as those described with respect to Figures 6, 9, and 10, aperture 505 is positioned below the minimum hydraulic volume fluid line (not shown) corresponding to the level of the hydraulic

volume Vh1 within the main body 530 when piston 572 is in full up-stroke. The primary accumulator hydraulic volume Vh1 interfaces with the fluid separator of the selected secondary accumulator to effectively combine the primary accumulator gas volume Vg1 with the selected secondary accumulator gas volume Vg2.

[0074] Referring now to Figure 17, an alternative embodiment of the present invention includes a pull-type hydro-pneumatic tensioner unit 628 having a primary accumulator housing 601 and a secondary accumulator housing including those described with respect to Figures 6, 9-11, 14, or 15. A piston 672 similar to the one described in Figure 16 moves axially within main body (barrel) 630 having inner bore 666. The piston 672 has a piston rod 632 extending from the lower side 682 of piston 672, the piston rod extends through a piston rod aperture 662 and through high-pressure seals associated with the aperture 662. The piston 672 also includes high-pressure seals 690. The combination, as described above and as to be described below, forms an enclosure of varying size depending upon primary accumulator pressure P1 and stroke position of the piston rod 632.

[0075] In the preferred configuration, the diameter of the piston 672 is substantially equivalent to the diameter of the inner bore 666 of main body 630, and the diameter of the piston rod 632 is preferably substantially equivalent to the inner diameter of the diameter of the piston rod aperture 662. The volume formed between the upper side 684 of the piston 672 and the inner bore 666 of the main body 630 forms a low-pressure annulus that is preferably vented to the atmosphere. The volume formed between the lower side 682 of the piston 672 and the main body inner bore 666 forms a portion of the primary accumulator 652 having a portion of the primary accumulator hydraulic volume Vh1. The main body 630 also includes an aperture 605 located adjacent the lower end of the main body to provide fluid communication between the main body portion of the primary accumulator and primary accumulator housing 601. The primary accumulator housing 601 preferably takes the form of an external cylinder or barrel. The primary accumulator housing includes aperture 603 in fluid communication with main body 630 through a fluid connection assembly 607 connected between aperture 603 of the primary accumulator housing 601 and aperture 605 of the main body 630. The bore 609 of the primary accumulator housing 601 includes a portion of the primary accumulator

hydraulic volume Vh1. The bore 609 of the primary accumulator housing 601 also includes at least a portion of the primary accumulator gas volume Vg1, depending on the configuration of the selected secondary accumulator. The amount of primary accumulator hydraulic volume Vh1 is dependent upon primary accumulator pressure P1 and stroke position of piston 672.

[0076] The tensioner unit 628 according to this embodiment can at least interface with either of the secondary accumulators described with respect to Figures 6-15. For illustrative purposes, the following discussion will be with respect to the secondary accumulator 121 described with respect to Figures 6-8. The primary accumulator housing 601 and secondary accumulator housing 101 are in fluid communication through a fluid connection assembly 608 connected to aperture 602 of the primary accumulator housing 601 and aperture 103 of the secondary accumulator housing 101. In this configuration, the primary accumulator 652 includes the inner bore of the main body (barrel) 630 and the lower surface 682 of piston 672, fluid connection assembly 607, the bore 609 of the primary accumulator housing 601, the fluid connection assembly 608, and the bore 109 of secondary accumulator housing 101 in combination with the primary accumulator side of the fluid separator according to the type of secondary accumulator configuration selected. The secondary accumulator 121 includes the inner bore 109 of the secondary accumulator housing 101 and the secondary accumulator side of the fluid separator according to the type of secondary accumulator configuration selected.

[0077] The configuration depicted in Figure 17 includes a hydraulic-type secondary accumulator similar to that described with respect to Figure 6, whereby primary accumulator hydraulic volume Vh1 provides the impetus to functionally combine the primary accumulator gas volume Vg1 with the secondary accumulator gas volume Vg2 to provide the tensioner unit 628 an effective total gas volume VgT substantially equivalent to that of the sum of the primary accumulator gas volume Vg1 and secondary accumulator gas volume. If a gas-type accumulator is used, such as that described with respect to Figure 14, the fluid connection assembly 608 would instead be connected to the upper aperture 602 of primary accumulator housing 601 in communication with the primary accumulator gas volume Vg1. Additionally, the maximum amount of primary accumulator hydraulic volume Vh1 can be configured under expected extreme operating

conditions not to exceed a level within the bore 609 of the primary accumulator housing 601 to that of communicating with the upper aperture 602. In this configuration, the primary accumulator gas volume Vg1 provides the impetus to functionally combine the primary accumulator gas volume Vg1 with the secondary accumulator gas volume Vg2 to provide the tensioner unit 628 an effective total gas volume VgT substantially equivalent to that of the sum of the primary accumulator gas volume Vg1 and secondary accumulator gas volume Vg2.

[0078] The invention has several advantages. The hydro-pneumatic riser tensioner units provide high nominal stiffness while limiting peak loads at extreme extended and retracted positions. In one configuration, the telescopic piston rod of the riser tensioner unit incorporates the bore or annulus of the piston rod as a secondary accumulator and incorporates a floating piston within the annulus of the piston rod. In other configurations, a separate housing having the bore or annulus is used to form the secondary accumulator. The total effective gas volume of the unit is increased by that of the secondary accumulator. During piston compression, the increased effective gas volume results in the load on the riser system increasing at a much lower rate and a reduced peak load. During piston decompression, the increased total effective gas volume results in a slower decrease in pressure and results in limiting the minimum tension applied to the riser system. Correspondingly, a smaller primary accumulator may be utilized.

[0079] In the drawings and specification, there have been disclosed a typical preferred embodiment of the invention, and although specific terms are employed, the terms are used in a descriptive sense only and not for purposes of limitation. The invention has been described in considerable detail with specific reference to these illustrated embodiments. It will be apparent, however, that various modifications and changes can be made within the spirit and scope of the invention as described in the foregoing specification. For example, optionally, the system could be entirely pressurized by gas only, using a separate lubricant for the seals, as known by those skilled in the art. Also, if full retraction is not required, the retraction stops used in the floating piston configurations could be eliminated. Further, the accumulator could be connected to the

riser and the piston rod to the vessel in reverse to what was described. Still further, the tensioner unit can be attached to the top plate at an intermediate point along the barrel rather than at the upper end as shown in figures. Correspondingly the tensioner unit can be connected to the support module lower support frame at an intermediate point along the barrel rather than at the lower end as shown in the figures.